the mean square $\sigma(E)$ and the entropy $\Delta(E)$ errors, the output code reliability $p$, and the information capacity $M$ of the designed DAT models.

Let us note in conclusion that the developed precision DAT model reflects to a sufficient extent the physical substance of the conversion error's and its components' formation process. It serves to simulate the effect of various factors of a production and utilization nature on the DAT precision possibilities by synthesizing the probability distribution laws of the component $E_2$ and, therefore, also of the entire conversion error $E$. This provides a purposeful control of the DAT quality.

**LITERATURE CITED**

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**DETERMINING THE ERROR IN REPRODUCING CONTINUOUS RANDOM SIGNALS BY MEANS OF PULSED FREQUENCY TRANSDUCERS**

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Frequency and digital transducers of pulsed frequency signals are now being increasingly used in measurement techniques [1]. In designing such devices it becomes important to evaluate their operating efficiency and determine their modulation error. Although these problems have been thoroughly investigated for discrete control systems with pulse-amplitude modulation, and the V. A. Kotel’nikov and N. A. Zhelezov’ theorems [2] show the relationship between the cutoff frequency or the correlation interval and the sampling period, systems with a pulse-frequency modulation (PFM) lack such recommendations.

Below we examine errors in reproducing original signals from a pulse-frequency sequence. These investigations are based on a computer simulation method.

Let us examine a PFM system (Fig. 1) consisting of the modulator 1, which converts the continuous random stationary function $y(t)$ into a frequency-modulated pulse train $\eta(t)$ and the restorer 2, at whose output the continuous function $z(t)$ is formed from the pulse train $\eta(t)$ (Fig. 2) with the error $\varepsilon(t)$.

The pulse train $\eta(t)$ instantaneous frequency corresponding to the pulse-emergence instant $t_i$ is determined by the relationship

$$F_{y}(t_i) = \frac{1}{T_{y}(t_i)}, \quad (1)$$

where the period $$T_{y}(t_i) = t_i - t_{i-1} = A[y(t)],$$ depends on the modulation law $A$ and the signal $y(t)$.

Several PFM laws are known [3]. For instance, in the majority of voltage-to-frequency converters [1] (2nd order modulators) the modulation law is a functional of the signal $y(t)$

$$\int_{t_{i-1}}^{t_i} y(t) dt = \frac{1}{k}, \quad (2)$$

where \( k = \frac{F_y}{y} \) is the scale factor.

It is possible to design transducers (first-order modulators) whose modulation law is a function of

\[
T_y (t_i) = \frac{1}{[k \cdot y \, (t_i)]},
\]

or

\[
T_y (t_i) = \frac{1}{[k \cdot y \, (t_{i-1})]].
\]

The restorer consists of the pulse train \( \eta(t) \) converter into the lattice function \( z (t) = \frac{1}{k \cdot T_y (t)} \) and the zero-order storage element at whose output the function \( z(t) = \frac{1}{k \cdot T_y (t)} \) is formed for \( t_i < t < t_i + 1 \). The system's precision is characterized by the error's mathematical expectation \( \mathbb{E}[\varepsilon (t)] \) and its mean square value \( \mathbb{E}[\varepsilon (t)] \). The quantities \( \mathbb{E}[\varepsilon (t)] \) and \( \mathbb{E}[\varepsilon (t)] \) are functions \( f_1 \) and \( f_2 \) of the modulation law \( A \) and the signal characteristics, including their distribution law \( g_y \), the error \( \sigma_y \), the mathematical expectation \( \mathbb{E}_y \), and a normalized correlation function \( r_y (\tau) \).

It is impossible to obtain a precise expression for the functions \( f_1 \) and \( f_2 \) in an analytical form, since the pulse train \( \eta(t) \) is represented by recursion relationships.

Let us simulate the PFM system on a computer, and represent its restoration errors as:

\[
\begin{align*}
\sigma_s &= \Phi_1 (\alpha, \gamma, g_y, r_y (\tau)) \, A, \\
m_z &= \Phi_2 (\alpha, \gamma, g_y, r_y (\tau)) \, A,
\end{align*}
\]

where \( \sigma_s = \frac{\sigma(\varepsilon (t))}{\sigma_y} \) and \( m_z = \frac{\mathbb{E}[\varepsilon (t)]}{\sigma_y} \) are the effective values of the mean square error and its mathematical expectation; \( \alpha = \frac{\sigma_y}{\mathbb{E}_y} \) is the depth of modulation factor; \( \gamma = \frac{T_{AV}}{\tau_0} \) is the distortion factor with \( T_{AV} \) being the mean pulse repetition frequency over the pulse train \( \eta(t) \), and \( \tau_0 \) being the correlation interval of the \( y(t) \) signals.

The object of simulation consists of determining the functions \( \Phi_1 \) and \( \Phi_2 \) and their replacement by approximate relationships suitable for practical application.

Figure 3 shows a block schematic of a PFM system's model. The parameter-setting unit 1 reacts on the random-signal generator 2, the modulator 3 with coefficient \( \gamma \) and modulation law \( A \), and the restorer 4, thus serving to obtain the signal \( y(t) \) with the given characteristics \( g_y \), \( r_y (\tau) \), and \( \alpha \).

Since the actual characteristics of the function \( y(t) \) realization can differ from the given ones, the unit 5 for evaluating the actual parameters \( \sigma_y \), \( \tau (\tau) \), and \( \tau_0 \) is used. The error-evaluation unit 6 serves to calculate the effective values of \( \sigma_s \) and \( m_z \). In order to raise the reliability of results, two simulation programs were compiled. In one of them the random process \( y(t) \) was obtained by means of the shaping filters method \[4\] with the correlation function

\[
r_y (\tau) = (e^{-0.76(\tau)} - 0.76 \cdot T_S \cdot e^{-\tau/T_S})/(1 - 0.58 T_S^2),
\]

where \( T_S \) is the shaping filters' time constant.

In the other program the process \( y(t) \) was formed by means of the canonical expansions method \[5\] with the correlation function \( r_y (\tau) = e^{-|\tau|} \). The signal distribution law \( g_y \) in both cases was assumed to be normal. The simulation program was written in ALGOL-60 and implemented on an "Odra-1204" computer.

Figure 4 shows graphs of the effective error values \( \sigma_{e_1}, \sigma_{e_2}, \) and \( \sigma_{e_3} \) for the modulation laws (2), (4), and (3), respectively. The interval \( \tau_0 \) was measured at the 0.1 level. The length of a single realization and the discreteness interval were obtained on the basis of the simulation error of 3-5%, and they amounted to \( T_0 = 100 \) sec and \( h = 0.1 \) sec. The discrepancy between the results obtained for \( T_S = 0.14, 0.35, 0.75, \) and 1.45 sec and the effective values amounted to 10%, i.e., the type of correlation function has an insignificant effect on the values of \( \sigma_e \) and \( m_e \). It will be seen from Fig. 4 that for

\[
\alpha < (0,1 - 0,2)
\]

the value of \( \sigma_e \) is virtually independent of \( \alpha \) and the relationships of \( \sigma_e \) to \( \gamma \) for \( \gamma < 0.1 \) can be approximated by the linear functions

\[
\begin{align*}
\sigma_{e_1} &= 10 \gamma; \\
\sigma_{e_2} &= 15 \gamma; \\
\sigma_{e_3} &= 5 \gamma.
\end{align*}
\]